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Solar stills: A review

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ABSTRACT

The availability of drinking water is reducing day by day; where as the requirement of drinking water is increasing rapidly. To overcome this problem there is a need for some sustainable source for the water distillation (purification). Solar still is a useful device that can be used for the distilling of brackish water for the drinking purposes. In this article a review has been done on different types of solar still.

Contents

1. Introduction

Fresh water is the essence of life and it is the most important constituent of the environment. Water is a basic human requirement for domestic, industrial and agriculture purposes. Supplying fresh and healthy water is still one of the major problems in different parts of the world especially in arid remote areas [1]. Solar stills can provide a solution for those areas where solar energy is available in plenty but water quality is not good. This device can be used for producing drinking water. Solar stills are cheap and having low maintenance cost but the problem of solar still is the low productivity [2]. Solar stills can be used for low capacity and self-reliance water supplying systems since they can produce drinking water by solar energy only, and do not need other energy sources such as fuel or electricity. There are many methods for converting brackish water in to potable water [3]. Some of the water distillation ways are described as:

In desalination the brackish or saline water is evaporated using thermal energy, and resulting steam is collected and condensed as final product. Vapour compression is the process of distillation in which water vapour from boiling water is compressed adiabatically and vapour gets superheated. This superheated vapour is first cooled to saturation temperature and then condensed at constant pressure and these pressures are derived by mechanical energy. Reverse osmosis is the process in which saline water is pushed at high pressure through a special membrane which allows water

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Nomenclature

A	Area (m^2)
C_w	Specific heat of water in the solar still (J/kg °C)
d_w	Depth of water mass (m)
H_S	Enthalpy of brine production
H_{SO}	Enthalpy of brine feed
H_D	Enthalpy of distillated water
H_{CA}	Coefficient of convective heat transfer from cover to atmosphere
I_0	Intensity of solar radiation
K	Thermal conductivity
L	Latent heat of water (J/kg)
P	Vapour pressure
T	Temperature
U	Overall heat transfer coefficient
C_p	Heat capacity (J/kg °C)
h_{cf}	Convection heat transfer coefficient between the glass and film
I	Solar radiation normal to glass cover (W/m^2)
M_{air}	Molecular weight of air (kg/kmol)
m	Mass per unit basin area (kg/m^2)
Pr	Prandtl number
q_{ba}	Heat transfer from the basin to the ambient (W/m^2)
q_{bw}	Heat transfer from basin to water in basin (W/m^2)
q_{ca}	Heat transfer from the film to the ambient (W/m^2)
q_{cg}	Heat transfer from the glass to the ambient (W/m^2)
q_{cw}	Heat transfer from water in basin to the glass (W/m^2)
Re_L	Reynolds number based on L
V	Velocity (m/s)
Vol_f	Volumetric flow rate of the cooling water per unit depth
T_{f1}	Film temperature at inlet
T_{f2}	Film temperature at outlet

Greek symbols

α	Absorptivity
α_s	Solar altitude angle
β	Incident angle
δ	Wall thickness (m)
ψ	Reference angle
γ	Azimuth angle
θ	Angle of still

Subscripts

a	Ambient air
g	Glass cover
w	Water
b	Basin linear
c	Collector
s	Still
d	Fresh water
e	Evaporator tube
L	thickness of part
wi	wick

molecules to pass selectively and do not allow to pass dissolved salts. In electrolysis method, water is passed through a pair of special membranes, perpendicular to which there is an electric field. Water does not pass through the membranes while dissolved salts pass selectively. In this article a review of different types of solar still has been discussed.

2. Working of a solar still

A solar still is a very simple way for distilling water, which is powered by the heat of the sun. Impure water is inserted into the container, where it is evaporated by the sun through clear plastic/glass. The pure water vapour condenses on top and drips down to side, where it is collected and removed [4]. A schematic diagram of simple solar still is shown in Fig. 1. It consists of an insulated black painted aluminum pan where impure water stands at shallow depth. A sloping cover of glass, supported by an appropriate frame, covers the pan and is sealed tightly to minimize vapour leakage.

A distillate through runs along the lower edge of the glass to collect the distillate and carried out of the enclosure through a plastic well insulating tube. The aluminum pan containing water is placed on an insulating base, while the wood frame is enclosed in the system [5]. The experimental part of the study consists of running the experiment with different sets of system and operating parameters. The analytical/numerical part includes the development of a mathematical model for solar still and then solving those mathematical models for the prediction of the solar still performance using computer simulation. In general a maximum efficiency of solar still is around 50% as compared to full insulation. A less insulation can cause a reduction of 14.5% in the efficiency. The increase of wind velocity from 0 to 3.6 mph yielded a slight reduction (2%) in the still performance.

3. Review of solar stills

Solar energy is an abundant, never lasting, and available on site and it is pollution free. However, the cost of its collection and utilization becomes high because it is diffuse, of low intensity, and intermittent and therefore, requires some kind of thermal energy storage. Murase et al. [6] developed an idea to improve the feeding system of a roof type solar still and was tested. The still is composed of bended heat penetrating plates at the centre having a channel for liquid flow below the crease of bending. A laboratory test apparatus of two effects having 500 mm × 500 mm heat penetrating area was designed and made mainly from polyethylene film. A test under cold conditions has proved the idea to be feasible. Toyama et al. [7] have studied the performance rating and efficiency of a solar still operating under different conditions. The three major variable factors in the still performance are the insolation, the wind velocity and the insulation of the system.

The distillation system can be classified under two categories: Passive and active. Malik et al. [8] have reviewed the work on passive solar distillation. Further work was carried out by Tiwari et al. [9], which also includes work on active solar distillation. Tiwari et al. [10] have carried out a study on the present status of research work on both passive and active solar distillation systems. Tiwari recommended that only passive solar stills can be economical to provide potable water.

3.1. Classification of solar stills

As a result of large interest for water purification, several types of solar still have been evolved. Some of them are single or multiple wick stills, the multistage flash distillation stills, solar film covered stills, and solar concentrator stills. Only the basin type stills using single effect distillation have been used for the supply of large

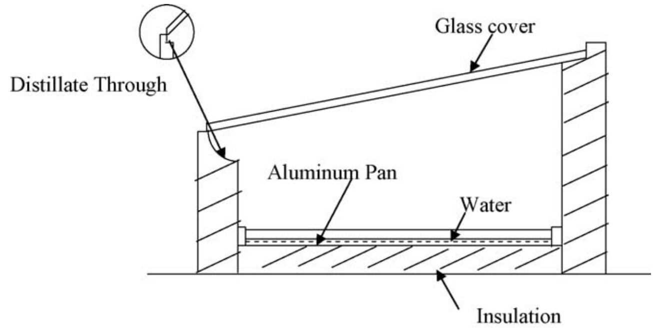

Fig. 1. A schematic diagram of a simple solar still.

quantities of water for isolated communities or for small supplies of water such as for battery charging and analytical purposes. There are several minor variations in the geometric configuration of single basin stills.

3.1.1. Roof type solar still

A roof type solar still is simple in construction. This still is composed of bended heat penetrating plates at the centre having channel for liquid flow below the crease of bending.

Bags of 500 mm^2 were made from polyethylene film of 1 mm in thickness. Each of them was penetrated by a tube of 15 mm in diameter at the centre and bended by stretching both sides at an arbitrarily given angle. Fibrous sheet of 1.3 mm in thickness as wick was attached inside the upper film of the bag. The dual holes were for manipulating the balance of liquid flow to both wings of the sheet. The side angle and inclination angle were fixed at 14.6° and 9.7°, respectively. Brackish water for purification is fed to the central tube from a head tank. The upper plate of the still is heated by infrared lamps through two sheets of frosted glass to attain uniform irradiation.

A portion of salt water is evaporated from the surface of fibrous sheet by receiving heat from the upper plate and condensed above the opposite surface. The condensed fresh water is collected in rectangular tubes at the both sides of the still as shown in Fig. 2. Murase et al. [6] have analyzed a specific problem associated with the feeding system of a roof type solar still and they have also analyzed a specific problem associated with the metallic materials; i.e. metallic materials would not be suitable for the construction of solar stills with low productivity. Copper Nickel alloys have been widely used for the tube material. Toyama et al. [11] in 1987 use the concrete slab for the upper plate to receive the solar irradiation and studied with the help of computer simulation. Toyama et al. [12] have developed a technology for trouble free operation of this type of still, i.e. to form a stable liquid film flow below the surface of wick. Therefore, a sophisticated idea was provided, i.e. the heat penetrating plate is bended at the centre line and has a channel for liquid flow below the crease of bending. A laboratory test apparatus of two effects having 500 mm × 500 mm heat penetrating area was designed and made mainly from polyethylene film. The upper surface was illuminated by infrared lamps in the intensity range between 240 and 650 W/m^2. The water to power ratio is of the order of 5 m^3/kWh, which was several hundred times that of conventional dual purpose systems. Concentration of salt water was 1% NaCl (by wt.) to trace bypassing and leakage, and feed rate varies from 0.7 to 1.0 g/m^2 s. The upper plate of the test still was heated by infrared lamps through two sheets of frosted glass to attain uniform irradiation.

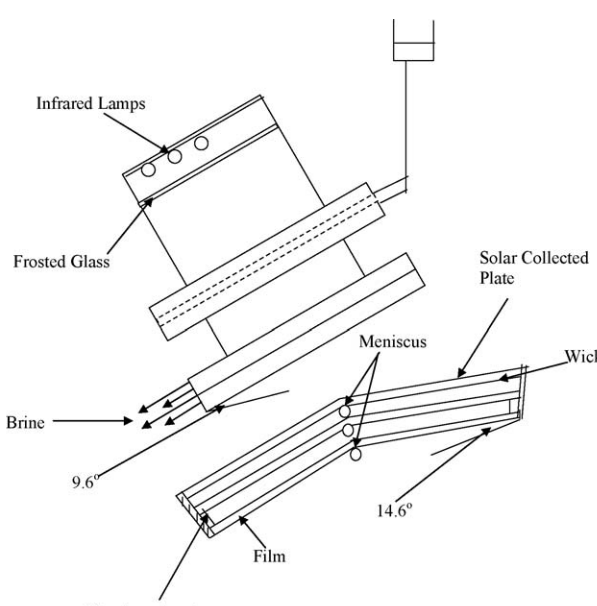

Fig. 2. A roof type solar still.

Many sophisticated process have continuously developed, and no sufficient material has still been found. Solar still does not permit such sophisticated process because it requires simple operation. Regarding this concept following assumptions were made in the analysis:

(1) Temperature distribution along the axial direction is uniform.
(2) Physical properties and constant values were identical to Toyama et al. [13].
(3) The absorptivity of the water and glass cover is negligible.

So, the governing equations for cover, plate, brine and water are given by Eqs. (1)–(4):

$$\rho_c L_c C_c \frac{dT_c}{dt} = \alpha_c I_0 + U_{pc}(T_p - T_c) - H_{CA}(T_c - T_A) - \sigma\varepsilon_{cs}F_{cs}(T_c^4 - T_{sky}^4) \tag{1}$$

$$\rho_p L_p C_p \frac{dT_p}{dt} = \alpha_p \tau_c I_o - U_{pc}(T_p - T_c) - U_s(T_p - T_s) \tag{2}$$

$$\rho_s L_s C_s \frac{dT_s}{dt} = H_{so}W_o + U_{ps}(T_p - T_s) - H_s W_L - H_o D - R_s D - (k/z)(T_s - B - T_D) - \sigma\varepsilon_{SD}F_{SD}(T_s^4 - T_o^4) \tag{3}$$

$$\rho_D L_D C_D \frac{dT_D}{dt} = R_D D + (k/z)(T_S - B - T_D) + \sigma\varepsilon_{SD}E_{SD}(T_S^4 - T_D^4) - U_{DA}(T_D - T_A) \tag{4}$$

Water to power ratio for such a hybrid system may be a key factor to determine optimum condition under the relationship. The average water to power ratio is estimated to be about 0.02 m^3/kWh.

3.1.2. Water film cooling over glass cover of a still including evaporation effects

The water film type of a solar still is simple in construction, a cheap and easy method for providing fresh water. It consists of a basin, glass cover having thickness 5 mm and cooling film thickness 1.3 mm. Continuous supply of water film is fed over the glass cover in order to reduce the glass temperature. Mousa et al. [14] have focus in achieving high efficiency with respect to temperature difference between the water in basin and glass cover. Several improvements have been proposed such as the use of forced convection, a dye, and external condensers. Authors found drawbacks, i.e. the need for a controllable air supply, the effect of

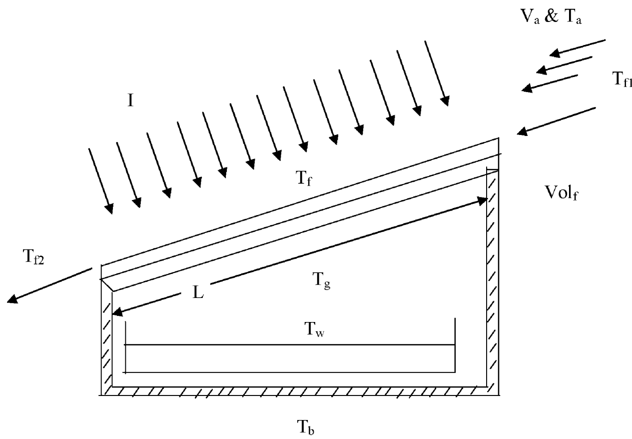

Fig. 3. A schematic diagram of water film type solar still.

dye on distillate quality and the need for an electric power supply. Incropera et al. [15] have represent the convective heat transfer between the cooling film and glass cover. Sherwood et al. [16] have represented heat transfer due to water evaporation associated with cooling. A schematic diagram is shown in Fig. 3.

The still efficiency is further improved by utilizing a part of water used for cooling in the form of preheated makeup water to the still. The cooling film also performs the important function of continuous self-cleaning of the glass cover. The presence of dirt and other types of filth on the glass cover greatly reduces the still efficiency. Continuous cleaning of the glass cover maintains high levels of efficiency. Proper use of film cooling parameters may increase the still efficiency up to 20%.

Energy balance for the still is performed for the following four components the basin, water in the basin, glass cover, and water in cooling film. Following assumptions were made during the analysis:

1. The mass flow rate of the film is assumed to be constant.
2. The mass fraction ranged from 0 to a maximum of 0.5%.
3. The absorptivity of the water and glass cover is negligible.
4. The cooling water inlet temperature T_{f1} was assumed to be equal to ambient temperature T_a. The energy balance is given in Eqs. (5)–(8):

$$m_b C_{pb}\left(\frac{dT_b}{dt}\right) = (1-r_g)(1-a_g)(1-a_w)I - q_{bw} - q_{ba} \tag{5}$$

$$m_w C_{pw}\left(\frac{dT_w}{dt}\right) = (1-r_g)(1-\alpha_g)\alpha_w I + q_{bw} - q_{rw} - q_{cw} - q_e - q_{mw} \tag{6}$$

$$m_g C_{pg}\left(\frac{dT_g}{dt}\right) = (1-r_g)\alpha_g I + q_{rw} + q_{cw} + q_e - h_{cf}(T_g - T_f) \tag{7}$$

$$m_f C_{pf}\left(\frac{dT_f}{dt}\right) = mr_f(C_{p1}T_{f1} - C_{p2}T_{f2}) + h_{cf}(T_g - T_f) - q_{ca} - q_{rf} - q_{ef} \tag{8}$$

The convective heat transfer (h_{cf}) between the cooling film and glass cover is calculated by using the equation for laminar flow over a flat plate [15], which leads to the convective heat transfer coefficient:

$$h_{cf} = 0.664\left(\frac{k_f}{L}\right) Re_L^{1/2} \times Pr^{1/3} \tag{9}$$

The q_{ef} represents heat transfer due to water evaporation associated with cooling.

3.1.3. Passive active solar still

An active type of solar still consists of a glass cover, basin, reflector and a pump. A glass cover having thickness, flat plate reflector length and basin insulation thickness are 5 mm, 1 m, and 1.5 mm, respectively. Brackish water is circulated to flat plate reflector; radiation from the sun is continuously falling on reflector where the brackish water gets heated and this preheated water is fed to the still. Due to sun radiation water gets evaporated and collected on glass cover from where it flows towards distillate channel. It is concluded that passive solar stills can be economical to provide potable or distilled water. On the other hand active solar still can be economical from a commercial point of view. Tiwari [17] has given climatic and design parameters for active solar still. Singh et al. [18] have also given the numerical computations for climatic parameters. The following assumptions have been made and a schematic diagram is shown in Fig. 4:

1. The solar distiller unit is vapour leakage proof and is in a quasi-steady state.
2. The heat capacity of the glass cover and insulating material of the solar still and collector are also negligible.
3. Each component of the system, i.e. bottom/size of the solar still and the collector is perfectly insulated including connecting pipes.
4. The flat plate collector is disconnected from the still using off sunshine hours.

Energy balance equations for glass cover; water mass and basin linear of an active solar still are given by Kumar et al. [11], which are as follows as Eqs. (10)–(12):

$$\alpha_g I(t)A_g + h_{1w}(T_w - T_g)A_w = h_{1g}(T_g - T_a)A_g \tag{10}$$

$$Q_u + \alpha_w(1-\alpha_g)A_w I(t) + h_w(T_g - T_w)A_b = (m_w C_w)\frac{dT_w}{dt} + h_{1w}(T_w - T_g)A_w \tag{11}$$

$$\alpha_g(1-\alpha_g)(1-\alpha_w)A_b I(t) = [h_w(T_b - T_w) + h_b(T_b - T_a)A_b] \tag{12}$$

$$Q_u = A_c F_R[(\alpha\tau)_e I(t) - U_L(T_w - T_a)] \tag{13}$$

The annual yield is at its maximum when the condensing glass cover inclination is equal to the latitude of the place. Therefore, annual yield significantly depends on water depth, inclination of condensing cover.

3.1.4. Multi-effect diffusion type solar still

Multiple effect diffusion type solar still has great potential because of high productivity and simplicity. Multiple effect diffusion type solar still consists of a flat plate reflector, casters for manual azimuth tracking and vertical multiple effect diffusion type still, which consists of a glass cover and number of vertical and parallel partitions with narrow gaps between partitions. The height of the still is 1 m. Length of the flat plate reflector is 1 m. Width of the still and flat late reflector is 1 m. A Diffusion gap between partitions is 5 mm. Air gap between the glass cover and first partitions is 10 mm. Absorptivity of the front surface of the first partition for sun ray is 0.9. Emissivity of glass cover is 0.9, and total number of partitions is 10. The saline water is fed to the wicks constantly. The angle of the flat plate reflector and azimuth angle of the still can be adjusted manually to absorb solar radiation on first partition effectively according to locations and seasons. Both direct and diffuse solar radiation, and the solar radiation reflected by the

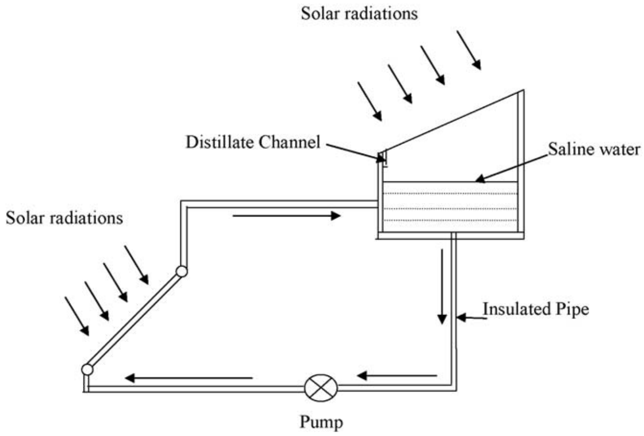

Fig. 4. An active solar still coupled with flat plate collector.

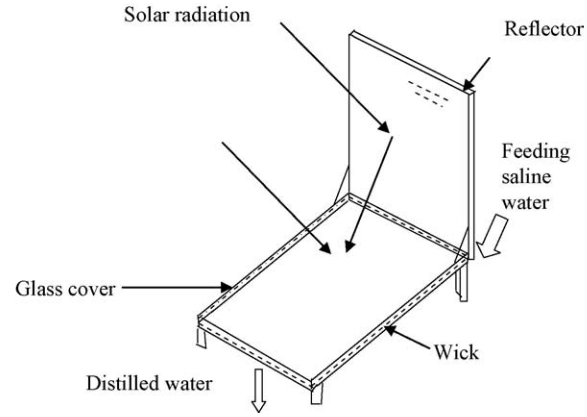

Fig. 6. Tilted wick still with vertical flat plate external reflector.

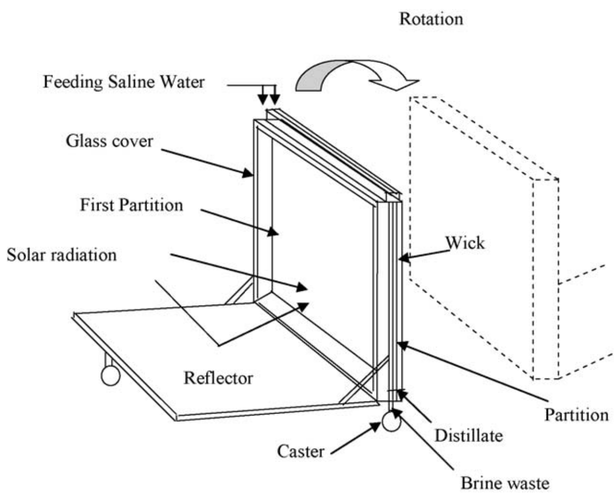

Fig. 5. A schematic diagram of a multiple effect diffusion type solar still.

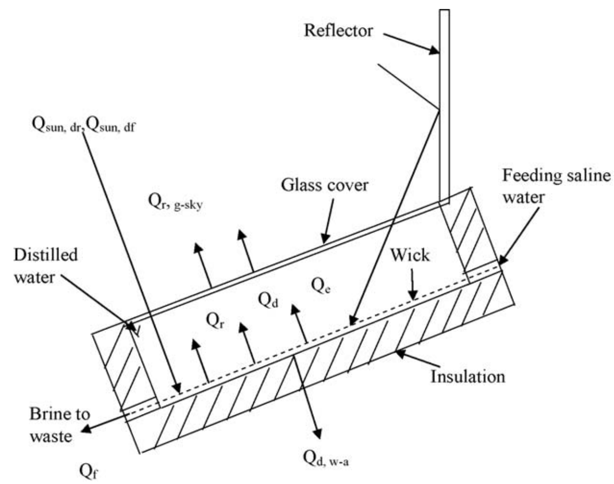

Fig. 7. Heat and mass transfer of the still.

flat plate reflector transmit through the glass cover and are absorbed on the front surface of the partition to cause the evaporation of saline water. A schematic diagram is shown in Fig. 5.

The water vapour diffuses through a humid air layer between the partitions and condenses on the front surface of the next partition. Latent heat from condensation is recovered to cause further evaporation from the saline soaked wick of second partition [19–22]. In this manner evaporation and condensation process is repeated on all partitions in diffusion type still to increase the productivity of distillate. Tanaka et al. [23] have carried out the study which is presented on a vertical multiple effect diffusion type solar still. Hiroshi proposed a very simple structure for local technicians in developing countries, which are operational with common materials. It is concluded that the productivity of the still can be increased by reducing the gaps between the partitions, evaporations and condensation process is repeated in all partitions. Tanaka et al. [24] reported that the discrepancy of the distillate productivity between outdoor experimental results and theoretical predictions for vertical multiple effect diffusion type still coupled with basin type is about 7%. Tanaka et al. [25] have given the numerical model to calculate heat and mass transfer rates in vertical multiple effect diffusion type still, which is coupled with a heat pipe solar collector [26]. Tanaka et al. [25,27] also indicated that vertical type of still has greater advantages over the inclined multi-effect diffusion type solar still but there is required an additional arrangement to absorb the solar radiation effectively, and proposed a vertical multi-effect diffusion type solar still coupled with basin type still.

3.1.5. Tilted wick solar still

Tilted wick still with flat plate reflector is very simple in construction. It consists of a glass cover, evaporating wick and a vertical flat plate external reflector of highly reflective materials such as mirror finished metal plate. Saline water is fed to the wick constantly. The direct and diffuse solar radiation and also reflected solar radiation from external reflector are transmitted through the glass cover and absorbed on to the wick. Tanaka et al. [28] have carried out the study to improve the productivity of tilted wick solar still by using flat plate reflector and also carried out numerical analysis for this purpose. Malik et al. [29] have also indicated one of their still, which can be useful to increase the productivity for the tilted wick solar still. Sodha et al. [30] have given their concepts to increase the productivity of the still. Similarly, Minasian et al. [31]

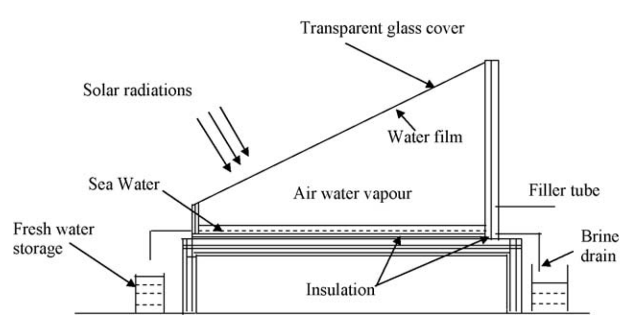

Fig. 8. A schematic diagram for sea water desalting.

Table 1
Comparison of different types of solar still used.

Types of solar stills	Geometry	Properties	Results	Advantages	Disadvantages
Simple solar still	Area = 500 mm × 500 mm, insulation = 1.5 mm, glass thickness = 5 mm	Intensity of insulation. Productivity steady state efficiency	Results obtained with the no insulation condition are more realistic since the presences of wind increase the energy losses from system.	Easy to install. Easy to operate. Less capital cost. Simple construction.	Efficiency is low. Productivity of water is low. Used in small area.
A roof type solar still	Base = 500 mm × 500 mm, bags = 500 mm^2, tube = 15 mm, fibrous sheet = 1.3 mm, side angle = 14.6°, inclination angle = 9.7°	Photocell temperature. Productivity solar intensity	Water to power ratio for such a hybrid system may be a key factor to determine the optimum condition. Main aim is to increase production.	Portable. Used in caravans recourse survey and military front. In laboratory.	Low performance. Used for small purposes.
Water film cooling over a glass cover of a still	Area = 500 mm × 500 mm, insulation = 1.5 mm, glass thickness = 5 mm	Steady state efficiency. Ambient temperature. Wind speed. Humid ratio.	For a conventional still, efficiency increases at low V_a and then decreases. A high value of h_{cf} results E. loss	More efficient than simple still. Productivity of water is higher.	Very sensitive. Glass temperature is main problem.
Passive active solar still	Area = 500 mm × 500 mm, insulation = 1.5 mm, glass thickness = 5 mm, pump. l_{re} = 1 m	Annual yield. Water depth. Inclination of flat plate collector	The performance of passive solar still in terms of hourly yield for different water depth.	Passive stills are more economical to provide potable water.	High capital cost. Depth increases efficiency decreases.
Multi-effect diffusion type solar still	Height of the still = 1 m. Length of the flat plate reflector = 1 m. Width of the still and flat plate reflector = 1 m. Diffusion gap between partition = 5 mm. Number of partitions = 10. Emissivity of glass cover = 0.9. Air gap between the glass cover and first partition = 10 mm. Reflectivity of the flat plate reflector = 0.95. Emissivity of the front surface of the first partition = 0.3	Solar radiation. Solar absorption. Time. Daily amount of distillate. Partitions. Overall productivity. Thickness of diffusion gaps between partitions. Feed rate of saline water. Reflectivity of flat plate reflector. Angle of flat plate reflector	The overall daily productivity is 1/5 of scale. The daily amount of distillate is largest on second partition and decreases from second to last partition. The overall daily productivity is larger on the winter solstice 39.7 kg/m^2 day than on spring equinox 34.2 kg/m^2 day since the sun rays are more inclined on the winter solstice than on the spring equinox, and this causes solar absorption.	Suitable for small purposes. More efficient when gap is very small. Mainly used in military fronts. Easy to operate. User friendly.	Diffusion gap between the partitions is the main problem. Air gap between the glass cover should be optimal.
Tilted wick solar still	Width of the still = 1 m. Length of the still = 1 m. Height of reflector = 0.5 m. Angle of the still = 30°. Azimuth angle of still = 0°. Diffusion gap between wick and glass cover = 10 mm. Absorptivity of wick = 0.9. Absorptivity of glass cover = 0.08. Reflectivity of reflector = 0.85	(1) Distillate production rate. (2) Solar radiation absorbed on wick. (3) Daily amount of distillate. (4) Angle of still. (5) Time	Distillate production rate as well as the solar radiation absorbed on the wick is greater for the still with reflector more than the still without a reflector during the time from 8 a.m. to 4 p.m. because the evaporating wick could not receive radiation from the reflector during the period.	Daily productivity of the still with reflector increases by 9% as compared to simple solar still. Productivity of water is more and used for economical purposes.	With out reflector productivity decreases. Wick is the main problem. Continuous feed of water is required for wick. Contamination due to wick always occur.
Solar still made up of tubes for sea water desalting	Table area = 1 m^2. Width = 0.5 m. Length = 2.0 m. Horizontal transparent tubes = 0.10–0.25 m, i.e. inner diameter. Horizontal tube = 0.01 m, i.e. inner diameter. Thin transparent plastic foil = 0.01 m	Daily energy efficiency of the still. The latent heat of vaporization. Temperature	Enhanced fresh water productivity is obtained with respect to conventional solar still in which sea water evaporation and water vapour condensation occur in one confined space.	Used for costal area. Easy to manufacture. Efficiency is higher than simple still. Fibrous material used. Due to tube contamination is much less.	Capital cost is high. Very sensitive apparatus. Due to fibrous material cost increases.

from energy management have given their view to increase the productivity of the still. A new concept of solar fraction to improve the effectiveness of an internal reflector for tilted wick solar still proposed by Tripathi et al. [32]. A schematic diagram is shown in Fig. 6.

Following assumptions were made during the analysis:

1. The solar distiller unit is vapour leakage proof.
2. The heat capacity of the glass cover and insulating material of the solar still and collector are also negligible.
3. Each component of the system, i.e. bottom/size of the solar still and the collector is perfectly insulated.
4. The absorptivity of the water and glass cover is negligible.

$$Q_{sun,dr} = G_{dr}\tau_g(\beta)\alpha_{wi} \times wl_s(\cos\theta + \sin\theta\frac{\cos(\varphi-\gamma)}{\tan\phi} \tag{14}$$

$$Q_{sun,re} = G_{dr}\tau_g(\beta)\rho_{re}\alpha_w \times l_m\frac{\cos(\varphi-\gamma)}{\tan\phi} \times \left(w - \frac{1}{2}l_m\frac{\sin|\varphi-\gamma|}{\tan\phi}\right) \tag{15}$$

Diffuse solar radiation absorbed on the wick, $Q_{sun,dr}$, can be determined with the assumption that diffuse radiation comes uniformly from all directions in the sky dome, and may be expressed as [33–37]:

$$Q_{sun,df} = G_{df}(\tau_g)_{df}\alpha_{wi} \times wl_s \tag{16}$$

$(\tau_g)_{df}$ is a function of the angle of the still, θ, and is calculated by integrating the transmissivity of the glass cover for diffuse radiation from all directions in the sky dome. This may be expressed as:

$$(\tau_g)_{df} = -2.03 \times 10^{-5} \times \theta^2 - 2.05 \times 10^{-3} \times \theta + 0.667\theta \tag{17}$$

The solar radiation absorbed on the wick $Q_{sun,dr}$ and $Q_{sun,re}$ when the sun moves north may be expressed as:

$$Q_{sun,dr} = G_{dr}\tau_g(\beta)\alpha_w \times \left[w\left\{l_s(\cos\theta - \sin\theta\frac{\cos(\varphi-\gamma)}{\tan\phi}) - l_m\frac{\cos(\varphi-\gamma)}{\tan\phi}\right\} + \frac{1}{2}l_m^2\frac{\cos(\varphi-\gamma)\sin|\varphi-\gamma|}{\tan^2\phi}\right] \tag{18}$$

$$Q_{sun,re} = 0 \tag{19}$$

Heat and mass transfer in the still is shown in Fig. 7. The energy balance for the glass cover and the evaporating wick may be expressed as:

$$Q_{sun,g} + Q_{r,wi-g} + Q_{d,wi-g} + Q_{e,wi-g} = Q_{r,g-a} + Q_{c,g-a} + (mc_p)_g\frac{dT_g}{dt} \tag{20}$$

$$Q_{sun,wi} = Q_{r,wi-g} + Q_{d,wi-g} + Q_{e,wi-g} + Q_{d,wi-a} + Q_f + (mc_p)\frac{dT_{wi}}{dt} \tag{21}$$

where $Q_{sun,g}$ and $Q_{sun,wi}$ are the solar radiation absorbed on the glass cover and evaporating wick, respectively. The daily amount of distillate of the still with reflector is about 14% greater than that of still with out reflector. The results for the autumn equinox are almost the same as those for the spring equinox since the loci of the sun on these days would be almost the same. On the summer solstice, the daily amount of the distillate of the still with reflector and the still with out reflector decrease inversely with an increase in the angle θ since the solar altitude angle becomes nearly vertical around noon and this causes a smaller projecting area on a horizontal surface of the still with a larger angle of θ. Therefore, the daily amount of distillate is smaller for the still with reflector than for the still with out reflector.

3.1.6. Solar still made up of tube for sea water desalting

Reali et al. [38] have focused their study towards sea water desalting. It is a very important method for costal area. Fresh water can be separated from sea water through different techniques or methods [39], but this technique requires suitable amount of energy inputs e.g. mechanical, electric and thermal energy [40]. It consists of blackened tray covered with a sloping transparent glass panel which is filled with sea water, with the help of the absorption of solar radiation releases water vapour which rises to the glass roof where it is recovered for use [41].

The two important features of a solar still are:

1. Technological simplicity.
2. Exploitation of a free heat source such as sun.

It is seen that overall productivity of the solar still is very low and various attempts are made to enhance their performance [42]. By using tubes of suitable material the main aim is to enhance fresh water productivity. Evaporator tubes, blackened in their lower half, are contained in an insulation tray on a table [43], and the condenser tubes are affixed on a support net underneath as schematically illustrated in Fig. 8.

Plastic tubes obtained from thin foils via plastic welding technology are given in [44,45]. Detailed information on properties of materials and on production technologies are summarized in the literature [46,47]. For several applications in the desalination sector, heat exchangers utilizing specially designed heat transfer surfaces which are made up of with high quality polymeric materials are an industrial base [47,48].

4. Discussion

Table 1 shows the comparison of different types of solar still used for the production of potable water from brackish water or saline water. All types of solar still have their utility for which they are used. In the comparison table solar stills are compared upon five different headings, i.e. Geometry, Properties, Results, Advantages and their respective disadvantages.

5. Conclusions

Solar radiation is used for the energy available by the sun, which means this system works on solar energy. There are many methods for desalination of brackish water in to potable water. Therefore, different types of solar stills are discussed for the production of pure water. A proper combination of cooling film parameters enhanced the still efficiency by 20%. In multi-effect diffusion model the productivity decreases about 15% with an increase in diffusion gaps between partitions from 5 mm to 10 mm. So for specific requirement there is a requirement to select solar still very continuously, based upon the local condition and operating conditions.

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